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Snow Accumulation and Melt Under Various Stand Densities in Lodgepole Pine in Wyoming and Colorado

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High-density forests accumulated less snow than low-density forests. Time of complete melt was prolonged less than a week by high-density forests. A 3-tree-heights-wide clearcut patch increased snow catch about 30% but also decreased snow in the downwind forest by an equivalent amount.

Keywords: Watershed management, land-use planning, clearcutting, forest thinning, snow hydrology, water yield improvement

MANAGEMENT IMPLICATIONS

Thinning dense stands of lodgepole pine or thinning to make small sheltered openings among trees allows greater snow accumulation. Forest management for increased wood production in lodgepole pine appears generally compatible with management for improved water yield in the Rocky Mountain region. Based on data presented here and in past studies, the greatest potential for increasing snow redistribution and water yield is harvesting in small clearcut patches, strips, or blocks. Greater water yields can be expected from clearcut areas because of reduced transpiration losses, a greater unit-area concentration of snowmelt water, and greater year-to-year carryover of soil moisture.

INTRODUCTION

Clearcutting in small blocks or strips is the recommended silvicultural system for optimum redistribution of snow to improve water yield in the subalpine pine forests of Colorado and Wyoming (Leaf 1975). This recommendation is founded on general evidence that snow accumulation is greater in openings and in small clearcut areas than under canopies of unbroken stands (Niederhof and Dunford 1942, Wilm and Dunford 1948, Goodell 1952, Berndt 1965, Hoover and Leaf 1967, Dietrick 1973, Gary 1975, Golding and Swanson 1978). The harvesting alternative believed to be optimal for snow redistribution is cutting not more than 50% of the forest at any one time, in blocks or patches about 5 tree heights (5H) in width, spaced at least 5H apart, and on sites protected from wind (Leaf 1975, Troendle and Leaf 1980).

Not so clearly known is the best combination of silvicultural and water management plans for the high-density, nearly stagnant, second-growth stands of lodgepole pine that will not be clearcut (Alexander 1974, Goodell 1964). This paper reports effects of varying stand densities on snow accumulation and melt in southern Wyoming and central Colorado.

STUDY AREA AND METHODS

Wyoming Study Plots

Plot Description

Plots were within an extensive lodgepole pine forest on a plateau about 9,000 feet above mean sea level, 2 miles southeast of Foxpark in southern Wyoming. The area is

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usually snow covered from late November, and there is little melt under forest cover until April. Snowpack water equivalent averages about 7.3 inches, usually about one-half of the annual precipitation (Peak and Crook 1967). Selected for study were an 80- to 90-year-old "dog-hair" stand (plot 1), a once-thinned stand (plot 2), a twice-thinned stand (plot 3), and a small, clearcut patch (plot 4), all within 0.25 mile of each other (table 1). Contrast between plot 1 and plot 3 is shown in figure 1. Study plot 4, approximately 3H wide by 5H long, was oriented with its long axis perpendicular to prevailing southwest winds (fig. 2). Plot 4 was also adjacent to plot 2.

Snow Measurements

In Wyoming from 1973 to 1977, snow measurements were taken near the time of maximum snowpack, usually about mid-March, and at irregular intervals during the melt season. A federal-type snowtube was used to collect snow samples, which were weighed to the nearest 0.1-inch water equivalent.

Twenty sample points were established along a transect through plots 1 and 3, with sample point spacing of 20 or more feet. Plots 2 and 4 were about 400 yards southwest of plots 1 and 3. Snow samples for plot 2 were obtained at 49 points spaced 10-20 feet apart. Snow samples for plot 4, immediately east of plot 2, were obtained at 5-foot intervals along seven crosswise transects, or from 133 locations (Gary 1980).

Colorado Study Plots

Plot Description

Plots were established in 70-year-old, second-growth lodgepole pine on the Fraser Experiment Forest, about 50 air miles west of Denver. The plots were on a relatively flat bench about 8,800 feet above mean sea level and 2 miles northeast of the Fraser headquarters. Dominant trees in the stand before thinning ranged from 50 to 55 feet in height and averaged 4.5 inches in diameter. Density ranged from 1,200 to 1,300 stems/acre, and basal area averaged about 140 square feet/acre. Four growing stock levels were established (primarily for other studies) over three sets of plots, each about 0.4 acre in size (fig. 3). A buffer strip 10 or more feet wide separated each plot. Table 2 shows average conditions for each growing stock level.

Table 1.—Average stand conditions for Wyoming study plots

Plot	Management	Tree height	Tree diameter	Density	Basal area
		feet	*inches*	*stems/acre*	*square feet/acre*
1	Dog-hair	33[a]	1.5[b]	10,000–20,000	149
2	Thinned 1940	35	5.4	800	125
3	Thinned 1940, 1967	37	6.1	435	105
4	Clearcut patch[c]	0	0	0	0

[a] *Dominant trees.*
[b] *Diameter range = 0.5–4.0.*
[c] *Before clearcutting same as plot 2; plot size 90 by 160 feet.*

Figure 1.—Contrast between twice-thinned stand (plot 3, foreground) and dog-hair stand (plot 1, background).

Figure 2.—Clearcut patch (plot 4) and adjacent once-thinned stand (plot 2).

Figure 3.—Thinned and unthinned lodgepole pine for one set of study plots in Colorado. Approximate basal areas (square feet/acre) are (a) 32; (b) 58; (c) 68; (d) 79; (e) 140.

Table 2.—Average cover conditions for Colorado study plots

Growing stock level	Basal area	Tree diameter	Density
---------- *square feet/acre* ----------		*inches*	*stems/acre*
40	32	6.8	127
80	58	6.2	276
100	68	5.8	371
120	79	5.5	467
Unthinned	140	--	--

Snow Measurement

In Colorado in 1978, 1979, and 1980, water equivalents were determined in the thinned lodgepole pine plots and in adjacent unthinned lodgepole pine near the time of peak snowpack. The same procedures were followed as in the Wyoming study. Samples were collected at 30-foot intervals along a transect running diagonally from the southwest to northeast corner of each plot. Seven snow samples were taken in each of 12 thinned study plots and one unthinned plot. Snow measurements were also taken every other week through the melt season of 1979.

RESULTS AND DISCUSSION

Effect of Forest Density on Snow in Wyoming

In Wyoming, the two higher density plots consistently had less snow than the lowest density tree-covered plot (table 3). The greater quantity of snow in the clearing resulted in part from an apparent redistribution of snow from the downwind forest (Gary 1980). An analysis of variance and mean separation for snow accumulation in the three tree-covered plots also indicated the lowest density (basal area 105 square feet/acre) plot had significantly greater ($P = 0.05$) quantities of snow than the two higher density plots. Snow accumulation differences between the two highest density plots were not significant, which indicated the dense dog-hair stand did not prevent large quantities of snow from subsequently reaching the soil surface.

Snowmelt relations for the Wyoming plots, which were determined only for the first two years of the study, are shown in figure 4. Observations indicated that melt rates were generally accelerated in the small clearcut patch and under the least dense (twice-thinned) forest cover. In 1973, snows in early May masked the earlier melt, but the figure illustrates that dense forest cover had little effect in prolonging late season melt. In 1974, there was no measurable snowfall after initial measurement on March 13 until May 9 (57 days). Average measured snow loss or melt over the period was:

Plot	Management	Snow loss
		inches
1	Basal area 149 square feet/acre	3.07
2	Basal area 125 square feet/acre	3.50
3	Basal area 105 square feet/acre	7.36
4	Small clearcut patch (3H by 5H)	7.06

Table 3.—Maximum snowpack water equivalents for various stand conditions and a small clearcut patch in Wyoming

	Basal area (square feet/acre)			
Year	149	125	105	0[a]
	inches of water			
1973	7.85	7.73	8.98	9.88
1974	7.67	7.72	8.51	10.21
1975	7.50	7.46	8.69	9.72
1976	7.42	7.27	8.41	9.43
1977	3.29	3.10	3.76	4.56
Average	6.75	6.66	7.67	8.76
Density effect (inches)[b]		−0.09	0.92	2.01
Density effect (percent)[b]		−1.3	13.6	29.8

[a] *Clearcut patch.*
[b] *Based on dog-hair stand.*

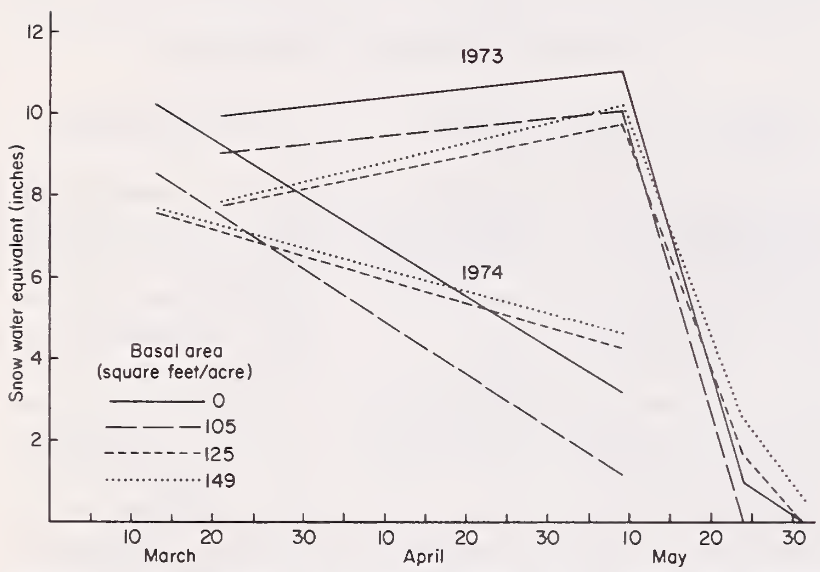

Figure 4.—Snowpack depletion under four cover conditions during contrasting years in Wyoming.

This indicates that average melt rate and/or snow loss in the small clearcut patch and lowest density forest plots was more than double that in the more dense forest plots.

Effect of Clearcut Patch on Snow in Wyoming

At the time of peak snowpack, the small clearcut patch (plot 4) always had significantly greater quantities of snow (Gary 1980) than was found in the surrounding once-thinned forest (plot 2). The distribution of snow across the 3H-wide clearing in the spring of 1975 is shown in figure 5. The contours of snowpack water equivalents (as percent of average snow water content in upwind forest) in and around the 3H-wide clearing illustrates the general zones of high (greater than upwind forest average) and low (less than upwind forest average) snow accumulation. These typical high accumulation zones were confined almost entirely to the clearing itself and oriented parallel to the long axis of the clearing. The contours also indicated effects of the 3H-wide clearing on snow accumulation were generally limited to a distance no wider than its width. These same general relationships were also evident in a variety of clearing widths (Gary 1980).

Volume computations, based on an "average-end area" technique and expressed as inches depth of snow water equivalents in and around the clearcut patch, provided a quantitative means to determine whether the greater quantities of snow within the patch actually represented an increase in snow accumulation (table 4). After the gains in the clearing were balanced against losses in the downwind forest, there was a slight reduction in snow water content attributable to the clearing. The 14.8% net loss in 1976 was the result of less snow catch in the downwind forest. The loss was most likely due to greater than usual wind scour and snow movement outside the measurement area.

From casual observations over several years, there has been little evidence to indicate that melting, evaporation, and sublimation are significant during midwinter; thus, we believe the analyses in table 4 correctly indicate a general equivalence of increased snow water content in the clearing and decreased snow water content in the downwind forest, as suggested by Anderson and Gleason (1959). Results from the small clearing are also in line with more qualitative findings for an entire watershed on the Fraser Experimental Forest (Hoover and Leaf 1967). Their inference was that snow catch remains the same but is distributed differently over a watershed, and that this is one probable cause for increased runoff resulting from timber harvesting in alternate clearcut strips on the Fool Creek watershed on the Fraser Experimental Forest (Goodell 1958).

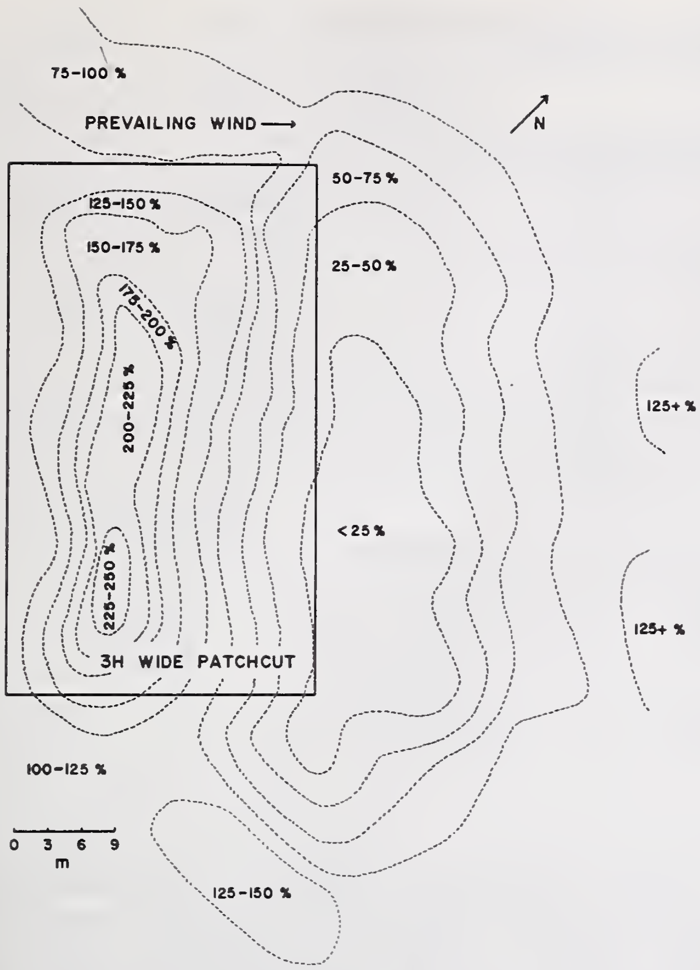

Figure 5.—Contours of maximum snowpack water content in the 3H-wide clearing during the spring of 1975. Percentages based on average snow water content (7.4 inches) in upwind forest.

Effect of Forest Density on Snow in Colorado

In Colorado, greater snow accumulation was also found under the thinned areas than under the unthinned stand (table 5). The succeedingly more open areas indicated a trend of relatively greater amounts of snow than in more dense areas, a trend similar to that observed in Wyoming. Goodell (1952), working in 40- to 45-year-old lodgepole pine on the Fraser Experimental Forest, also demonstrated that thinning of dense forest stands appreciably increased the net precipitation received on the forest floor. Mean values as presented in table 5 were quite variable, however, and changes in water equivalents given in table 5 were not statistically significant ($P=0.05$) for the years observed.

Harvesting on the nearby Fool Creek watershed in Colorado (Troendle and Leaf 1981) also had a nonsignificant ($P=0.05$) 12% increase in total snowpack for 25 years following treatment. The 12-13% increase in net accumulation demonstrated on Colorado and Wyoming study areas is probably due in part to interception savings rather than a redistribution phenomenon that occurs between an open area and its downwind forest. These net increases are also comparable with other estimates of interception loss.

Snowpack depletion for study plots in Colorado is shown in figure 6. After mid-April, rate of snow depletion among the four thinning levels were relatively uniform, and complete snowmelt occurred at about the same time for all thinned plots. Average melt rates of the four thinning levels were from 20% to 60% higher than the unthinned stand:

	Thinned	Unthinned
	--------- *inches/day*	---------
April 2-19	0.091	0.075
April 20-30	0.323	0.179
May 1-16	0.227	0.156

The periods of higher melt rate in the thinned areas shortened the time of complete melt about 1 week. These findings were also about the same as those observed in Wyoming.

SUMMARY AND CONCLUSIONS

Snow accumulation was observed under three densities of second-growth lodgepole pine and in a 3H-wide clearcut plot for 5 winter seasons in southern Wyoming. Peak snowpack was also determined for 3 years and snowmelt for 1 year under four thinning levels in second-growth lodgepole pine on the Fraser Experimental Forest in central Colorado.

Table 4.—Volume of snow water equivalent (reported as depth of water) in the upwind forest, 3H-wide clearcut patch, and downwind forest[a]

Year	Upwind forest	Clearcut patch	Downwind forest	Net difference[b]	
	inches of water				*percent*
1973	7.43	10.10	5.74	+0.73	+9.8
1975	7.44	9.97	4.99	−0.12	−1.6
1976	7.32	9.69	4.03	−1.08	−14.8
1977	3.18	4.71	2.18	+0.28	+8.8

[a] *Adapted from Gary 1980.*
[b] *In computing the net differences, factors were included to adjust for the plot areas measured: upwind forest, 12,000 square feet; clearcut patch, 10,800 square feet; and downwind forest, 12,000 square feet.*

Table 5.—Maximum snowpack water equivalents as affected by thinning in 70- to 75-year-old lodgepole pine in Colorado

Year	Basal area (square feet/acre)				
	140[a]	77	69	58	40
	inches of water				
1978	9.90	9.10	9.90	9.60	10.20
1979	8.71	8.91	9.06	9.78	10.37
1980	10.50	11.17	11.25	11.59	12.09
Average	9.70	9.73	10.07	10.32	10.89
Density effect (inches)[b]	-	0.03	0.37	0.62	1.19
Density effect (percent)[b]	-	0.3	3.8	6.4	12.3

[a] *Unthinned stand.*
[b] *Based on unthinned stand.*

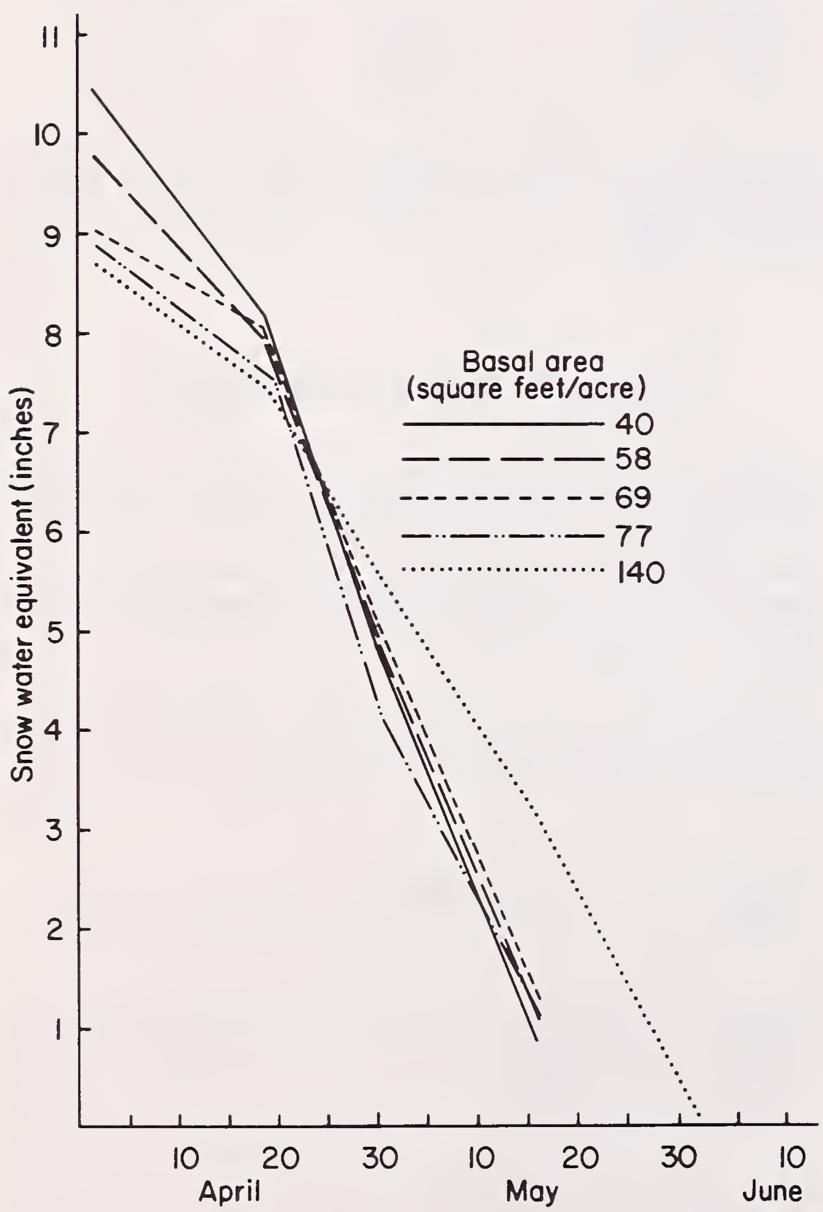

Figure 6.—Snowpack depletion under five cover conditions during the spring of 1979 in Colorado.

In both Wyoming and Colorado, the lowest density study plots accumulated greatest amounts of snow. The greater quantities of snow were apparently due in part to less interception loss than in the more dense study plots. It was also apparent that snowpack increases were considerably less than those observed in the small clearcut patch. Small clearcut patches appear to be the best way to achieve significant snow redistribution in the lodgepole pine forests of Wyoming and Colorado.

In Wyoming, the advantage of dense forest cover in prolonging snowmelt was greatest during the early part of the melt season, April through early May. In Colorado, the snowmelt period was similar under four thinning levels and shortened less than 1 week in comparison to unthinned areas.

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